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EYE MOVEMENTS IN HUMAN ACTIVITY AND IN ITS STUDY

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16. Abstract

Some preliminary notions concerning eye movement research are briefly set forth. Two types of investigations are discerned: one where eye movements themselves are the object of study, and the other where the analysis of eye movements is used as a method of studying other processes. The concepts of stimulation, visual mechanism, and problem are defined as being the fundamental factors in a study of eye movements. Finally, the development of the study of fixation optokinetic nystagmus is traced.

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EYE MOVEMENTS IN HUMAN ACTIVITY AND IN ITS STUDY

Yu. B. Gippenreyter

The numerous investigations on eye movements which are available at the present time can be divided into two large categories. The first category includes the studies in which the eye movements are the topic of the investigation. In these studies, the various types of eye movements are examined, their quantitative and functional characteristics, the physiological mechanisms, etc. The studies in the second category use the analysis of eye movements as a method for investigating other processes. These are of course primarily the processes of visual perception, which in principle cannot be investigated by "direct", objective recording. Although less frequently, attempts are being made to examine eye movements in the context of other types of activity, for example thinking, and through them obtain data on the structure and properties of processes in human activity which are not necessarily visual. Understandably, the studies in the second category have a more general psychological meaning, although investigations of the first type are no less important. /3*

When a certain process is used as a method of investigation, the assumption is made a priori that it is related by complex relations with other processes and phenomena. This is true for eye movements. If they are to be used in order to understand the processes of visual and nonvisual activity, it is imperative

* Numbers in margin indicate pagination in original foreign text.

to investigate thoroughly the hypothetical construction of underlying mediating relations between eye movements and these processes. Our purpose in this article is to examine a system of this type of relations.

The best way to highlight the indicated relationship is /4
to ask the question: what determines the eye movements? Three types of factors can be enumerated as a preliminary answer.

First of all, it is stimulation. Examples of the decisive effect of stimulation are various reflex acts: sudden jerks of the eyes in response to a bright flash or an unexpected sound (quadrigeminal start reflexes), jumps of the eyes in response to an unexpected peripheral stimulus (oculomotor component of the exploratory reaction), "spastic" fixation in pathology, etc. This is the most obvious factor and the most unconditional, but it is of limited importance, because it rarely determines the eye movement in itself. On the whole, it is always present, but it is mediated by two other factors.

One of these is the special visual mechanisms. The clearest example of their action is the adjusting or "guiding" eye movements. The cause of these movements, as is well known, is the functional heterogeneity of the retina, and the presence in it of a small area of clear vision — the fovea.

Finally, the third and most essential factor which as a rule modifies the action of the two former factors is the problem. Let us dwell on the problem in more detail.

From the standpoint which interests us, all problems can be divided into three large categories: oculomotor, visual proper, and problems which are nonspecific as far as vision is concerned, which can be called "general". As an example of the latter, we have presented thinking problems; these can be mnemic, motor, etc. Despite the variety of such problems, they can be united in one category due to the common structural role of eye movements.

When the subject solves an oculomotor problem, i.e., he acts in accordance with an instruction of the type, "Turn the eyes to one side", "Fixate the dot", "Outline the contour", "Pass with your eyes over the mold", etc., then his eye movements appear as actions in the accurate sense of the word.*

If we attempt to analyze the recordings of eye movements and to answer the question, why do the eyes perform a certain movement in a given moment, it is sufficient to consider the problem and the concrete stage of problem solving (of course, considering the peculiarities of the object), which incidentally are well reflected in the subjective report of the subject.

Thus, eye movements appear as *actions* in the problems of the /5
first type. In problems of the second type, the visual problems, eye movements become *operations*.** We call these "*first order operations*", since they serve the main actions directly. The problem-solving proper takes place due to the work of visual mechanisms which make up the underlying visual actions: the eye movements service the latter, are subordinated to them, and are determined by them. ***

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* A.N. Leont'yev. Problemy razvitiya psikhiki (Problems of Psychic Development), Moscow, "Mysl'", 1965, pp. 514-515.

** A. N. Leont'yev. Problemy razvitiya psikhiki (Problems of Psychic Development), pp. 514-515.

*** From this viewpoint, the term "perceptive actions" which is frequently used as a synonym for eye movements, seems to us inappropriate (Zaporozhets, 1967; Zinchenko and Vergiles, 1969 and others). The purpose in visual perceptive problems is not the movement of the eye, but rather obtaining an elaboration of visual information. The eye movements characterize the means by which this purpose is attained.

Let us clarify this by means of an example. When the subject is assigned the problem, to detect a weak signal against a background of noises, as is done in the work of L. V. Borozdina* then its solving takes place in stages, in the form of consecutive actions. First there is the search and the elaboration of a hypothesis, then the testing of the hypothesis, and the making of a decision. Various visual mechanisms are involved at various stages of the work, and as a result of this, the motor behavior of the eyes changes. At the stage of the search, it is important to catch the signal, and the subject gazes at a relatively wide operational field. Correspondingly, his eye movements are sweeping and are distributed over the whole field of the object. At the stage of verifying the hypothesis, it is important to enhance the signal-hypothesis by some means. It appears that the visual system can do this both by static and by dynamic methods. In the first method, prolonged fixations on the signal are observed, while in the second — either jumps in the region of the signal (the eyes seem to test the signal by various parts of the retina), or slow drift. At this stage, the subject sometimes resorts to testing the signal (eliminating false hypothesis) by evaluating not the absolute brightness of one signal, but rather the relative brightness of two or three assumed signals, which is accompanied by repeated jumps in the area of the latter.

Thus, we see that the concrete visual action or the stage of problem solving determines the character of the visual mechanism (the detection — and the wide operational field, absolute or relative evaluation of brightness — and the corresponding mechanisms of signal enhancement), while the latter determines the eye movements. Let us pass to problems of the third category,

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* Here and further on, see the article in the present collection for finding the year of publication (ed.).

which are called "general". Two different cases are possible which are different in principle, as encountered in our work.

In the first case, the eye movements are part of the structure of the main activity and play in it the part of <u>second order operations.</u> In the second case, the eye movements do not bear any functional load, and represent an <u>activity epiphenomenon</u>. /6

Let us examine both cases in more detail. The general actions (actions for solving the general problem) can be built on the basis of both visual and nonvisual information. For example, reference is made to visual and proprioceptive afferentation of movement, visual and auditory memory, image and logical thinking, etc.

The utilization of visual information can assume various forms and degrees. For example, the movement can be controlled by "current" visual stimulation, and by image representation; with increasing automation of the movement, the visual control may gradually diminish, yielding its place to proprioceptive control, etc. Our first case includes the actions in which the visual afferentation takes part to any extent or in any form. Here eye movements are mediated twice. First by the concrete type of visual mechanism, and second — by the "specific importance" or role played by the latter in the process of movement control. This importance or role can change from problem to problem and even in the course of solving the same problem. In each concrete case, they require special definition and investigation. Evidently, in the general problems, the visual processes play the role of operations, inasmuch as they serve the main actions; the eye movements serve vision, i.e., they appear as operations of operations or second order operations.

The second case is formed by general problems or stages in their solving where visual afferentation is entirely absent or where eye movements are observed in a certain form. Examples are protracted fixations in profound mental work (Gippenreyter and Kareva, 1969; Zinchenko, Vergiles, 1969 and others), the tracking movements of level I (Gippenreyter, Smirnov, 1971; Gippenreyter, Romanov, 1970), etc. How should we understand the nature of these movements? In our view, these are a good example of processes which occur "due to the structure of the organ" (Darwin, 1953). The idea that not all processes in the organism are useful is still upheld today (see, for example, Naprimer, Vasil'yev, Gel'fand, Guberman andShik, 1969). Certain processes which accompany useful acts are simply the <u>consequence</u> of the multiple relations of a complex system. They have no direct relation to the purpose of the activity and cannot be understood by it. In order to explain them, we have to go down one level and examine the morphological and functional relation of that "substrate" on which the main process is unwinding. In these cases, the eye movements are really characterized by low level reflex acts. We evaluate them as <u>psychophysiological</u> functions.

For the sake of clarity, let us choose the method of representation of perceptive processes by means of block diagrams (see, for example, Solley, Murphy, 1960; Neisser, 1966; Sperling, 1967, Gibson, 1969; Zinchenko, 1971 and others). However, we do not intend to derive new blocks, but want instead to represent in a clear way the above-described relationships as well as some new ones. Four obvious blocks can be immediately introduced; the problem, the visual object or stimulus, the visual mechanisms proper, and the eye movements. Inasmuch as the problem determines the type of the relationship, it must first of all be defined, i.e., whether oculomotor, visual or "general".

Let us start with the oculomotor problem (Figure 1). Here an arrow should be drawn from the problem to eye movements, 1. This represents the main (oculomotor) action. The eye movements (except for the case of movements in the dark) are usually visually afferent. Consequently, we can represent the requirement from eye movements to the visual apparatus, 2. The visual system adjusts itself to a given stimulus — only the one which is required for afferentation of the eye movements, 3, and the visual mechanisms operate in a definite manner depending on the concrete features of this stimulation, 4. It is advisable to represent the block "visual object" (S) as a set of stimuli: $x_1, x_2, x_3, \ldots\ldots, x_n$; it can be shown that only one or a group of these stimuli are relevant to the problem.

Let us examine an example which illustrates the described relations.

In one of our earlier investigations (Gippenreyter, 1964), we suggested to the subject to, "pass with the eyes" along a horizontal line from one end to a certain section to the other. The given line was one of several parallel lines which were all alike. The totality of the lines formed a uniform horizontal lattice. The tightness of the lattice was varied. It appeared /7
that the magnitude of the "steps" taken by the eyes also changed: the tighter the lattice, the smaller the amplitude of the jumps. In this connection, the term "afferentational field" was introduced (Leont'yev and Gippenreyter, 1966), which designates a certain region of the field of vision in the limits of which the eye movements can be conducted afferently. Obviously, in order for the jumps to be performed without leaving the given line, its continuation has to be seen clearly by the eye. The tighter the object, the closer is the limit beyond which all the lines merge due to the known decrease in the resolving ability of the retina at the periphery, in other words, the narrower did

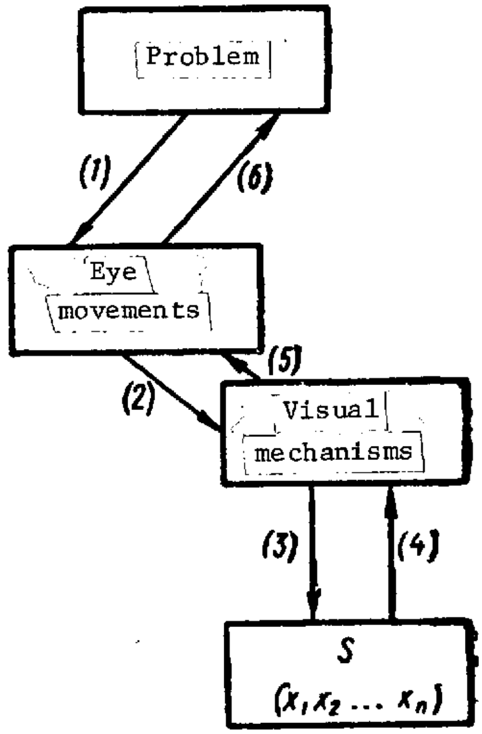

Figure 1.

the afferentation become. As a result, the amplitude of the jumps was reduced.

Thus, the problem facing the subject led to horizontal movements — jumps of the eye, 1; these movements "gave the order" to the visual system to afferent them, 2; by distinguishing the continuation of the line, 3; the tightness of the object determined the magnitude of the afferentational field 4; which in its turn, determined the amplitude of the eye movements, 5; the eye movement led to solving of the problem, 6.

Attention should be paid to the presence in our diagram of processes characterized by two opposite courses; so as to say, active and passive. The first course refers to processes which are designated by arrows 1, 2, 3; the second refers to arrows

4, 5, 6. It can be shown that only processes of the second direction "really" exist, since all of them start with the action of the stimulus and ends with a jump or a series of jumps of the eye. However, such a representation based on the traditional S-R relation brings to the fore all the drawbacks of the latter. This cannot explain why the process assumes a certain course and why does it start at all. The processes of the active course are materialized in the form of a "coded model of the consumed future" (N. A. Bernshteyn), problems of goal realization; processes of adjustment, command signals and correction signals, etc. The passive course processes follow "orders" from above, and accord them a concrete aspect and shape depending on the external conditions and the available means of the organism.

Let us pass to visual problems. As mentioned above, these lead to visual actions. Typical examples of such actions are detection, discrimination, metric evaluations, recognition, etc. Inasmuch as the aspect of the main actions, like their appearance, is determined by the problems, let us draw arrow 1 from the problem to the visual mechanisms (Figure 2). As in the previous diagram, stimulation 2, which is relevant to the given visual action, and the effect of the concrete aspect of this stimulation on the visual mechanisms, 3, should be indicated. /9

It is important to state what we understand by "visual mechanisms proper". These are morphological or functional systems, as well as the processes in these systems, which provide for any visual effect, beginning with the simple sensation of light, up to complex forms of object perception. It is advisable to divide visual mechanisms into two large categories which we shall arbitrarily call "morphophysiological" and "psychophysiological". The first mechanisms are congenital and are elaborated unconditionally. They reflect the morphological properties of the organ. Examples are the resolution ability of the retina, lateral inhibition, receptive fields, etc. These mechanisms make the classical object of physiological vision.

The "psychophysiological" mechanisms, as opposed to the morphophysiological ones, are those mechanisms which appear as a product of individual experience and are determined by the activity at the level of the subject. In the physiological literature, they are in the best case mentioned as "higher processes" or "effect from the higher centers"; however, no adequate physiological descriptions are available. Much greater attention has been traditionally given to these phenomena in psychology. As examples we can indicate the mechanisms which underlie the constancy and selective adjustment of perception, recognition on the basis of complex indicators (Glezer, 1966), and so forth. Characteristic features of these mechanisms, along with the fact that they are formed during the life of the individual, are the subordination to the problem and random control. The influence of the problem is clearly reflected, for example, in the magnitude of the operational field of vision; due to this fact we relate this mechanism to the category of "psychophysiological". Under identical external visual circumstances, and change of the problem can lead to reduction of the operational field from several tens of angular degrees (in the problem of detection) to several angular minutes (in the problem of attentive examination). With regard to the possibility of voluntary control, or of the subject's intervention, this depends on the degree of automation of the corresponding process. For example, at the basis of perception constancy lies to a great extent an automatized process, according to this sign, was classified by G. Helmholtz with the "unconscious mental /10
conclusions". However, as shown by the investigations, these can be partially "overcome" by the analytical system of the observer, (Brunswik, 1944). The subject's influence is also

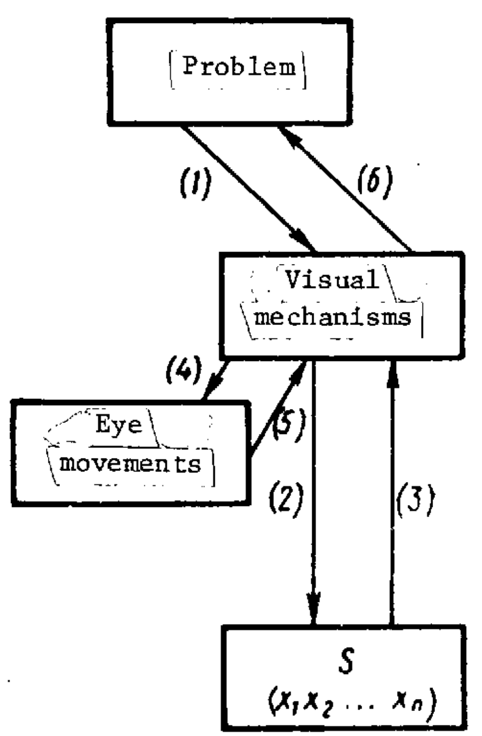

Figure 2

expressed in the possibility of random inclusion or variation of the described mechanisms. Thus, we repeatedly observed in our experiments alternative methods of size estimation (Borozdina and Gippenreyter, 1969), brightness of the signal (L. V. Borozdina), coordinates and speed of the signal (T. M. Buyakas, V. V. Lyubimov), reversal of ambiguous and discrimination of disguised figures (Gippenreyter and Sedakova, 1970; V. Ya. Romanov), which can be arbitrarily called "static" (taking place under conditions of eye fixation) and "dynamic" (accompanied by eye movements). It appeared that the subject could pass from one method to the other, not only depending on the conditions of the problem but also at random.

A very important matter is that of the interaction between "morphophysiological" and "psychophysiological" mechanisms. Investigation of this question is imperative for a correct understanding of the double determination of visual mechanisms, from the part of stimulation and from that of the problem (see Figure 2). However, this question deserves special attention, and we shall not dwell on it here.

Let us now include in our diagram the eye movements. Naturally, in the case of visual problems, they are determined by the type and conditions of operation of the visual mechanisms. The latter determine the very need for eye movements, both with respect to their initiation and with respect to their concrete form and extent of utilization. Consequently, let us draw an arrow from the visual mechanisms to the eye movements, 4; this expresses the service role of the eye movements, their functioning as <u>operations.</u> The connection in the reverse direction, 5, reflects the changes which the eye movements introduce in the working conditions of the visual mechanisms; finally, arrow 6 reflects the results of the latter's work.

Let us analyze an example of such a case. In the investigations of M. V. Borozdina and Yu. B. Gippenreyter (1969), the subject was asked to give a comparative estimation of the length of two segments on a horizontal line. If the segments were largely different, the problem was solved instantaneously within one fixation; if the difference was a threshhold one, then the motor activity of the eyes was displayed. The eyes started to "work" alternatively with each segment, doing several jumps, especially in their middle region. From this example, we see that the problem determined the form of the visual action (comparative estimation of the size), 1, and accordingly adjustment took place to the relevant stimulation (length of the segments), 2*;

* Let us recall that in the previous example, where the subject dealt with segments of horizontal lines as well, the relevant stimulation was entirely different, i.e., <u>continuation</u> of the line, and only to the right of the fixation dot (inasmuch as the jumps were performed in one direction, from the left to the right).

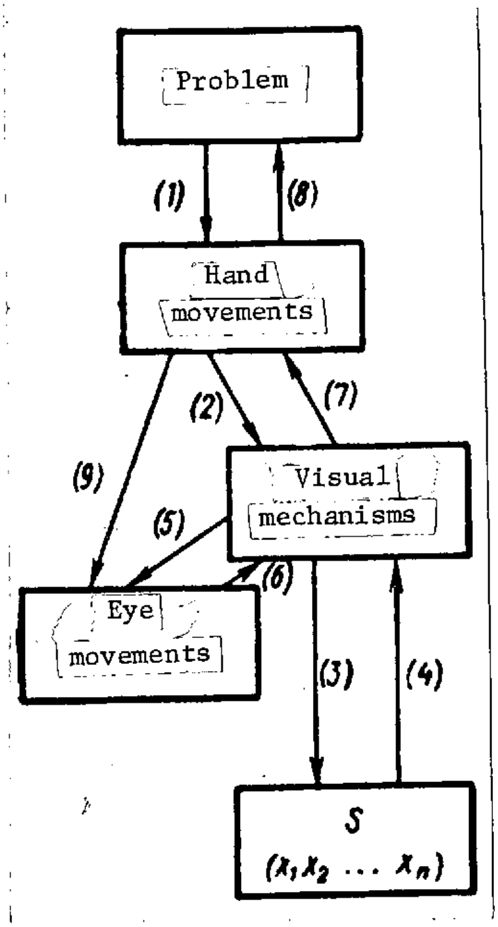

Figure 3a

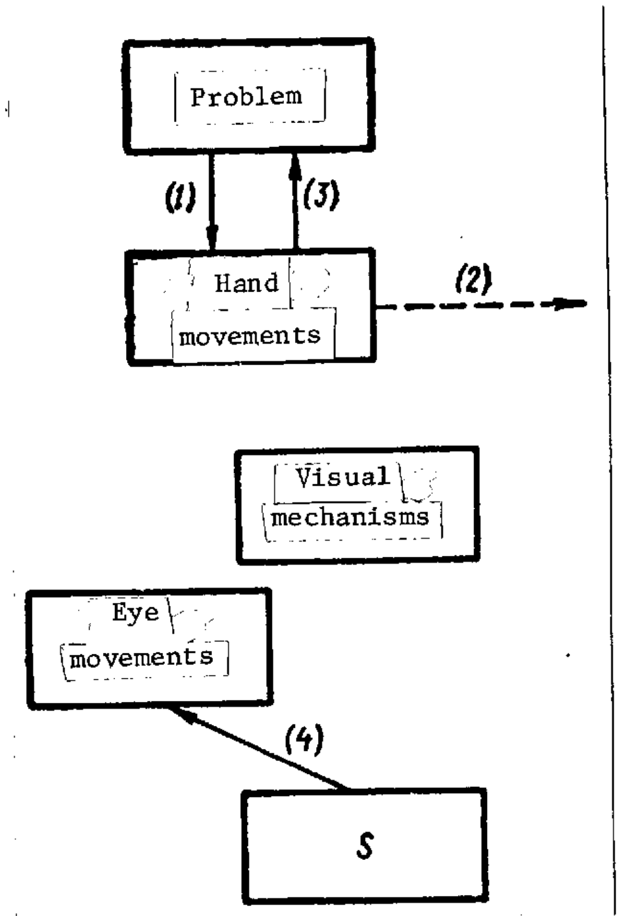

Figure 3b

the objective ratio of the length of the segments determines the concrete mechanism and the method by which the problem was solved: by a rough estimate, simultaneously, 3, or by accurate estimation of each segment using eye movements, 4. It is natural to assume that in the second method, each jump facilitated greater accuracy of the information about the length of the segment, 5, which was part or stage of the problem-solving, 6.

Let us now turn to general problems. In this case, the diagram will contain five blocks; in addition to the four previous ones, we shall have to introduce a system for solving the main problem. Let us take for example, the hand movements taking into account the manual motor problem (Figure 3a). Connections 1 and 8 represent the main actions — hand movements. If the movements of the hand are visually afferented, connection 2 appears, which expresses the requirement to the optical system /12 from the system of hand control. In order to lead to afferentation of the manual actions 7, the visual system has to provide for several estimations (distances, speed and so forth); these will represent first order operations. The connections of the visual mechanisms with the object and eye movements are preserved, however, they change their degree. In particular, arrows 5 and 6 (equivalent to arrows 4 and 5 in Figure 2) represent here second order operations instead of first order.

Let us give an example of the described relationships. In the experiments of T. M. Buyakas, it was suggested to the subject to bring together a visual target with a mark on a screen by means of a visual handle. The mark was stationary, while the target moved in an unpredictable manner under the effect of a noise. The connection between handle and target could be either "rigid" (first set of conditions) or delayed (second set of conditions). It appeared that the movements of the eyes in the two cases were different in principle. In the first set of conditions, the eyes were mainly in the region of the mark, ignoring the movement of the target; contrarily in the second set of conditions, the eyes followed the target, moving together with it. This result led to the assumption that under the described conditions, the subjects worked with different operational fields: with a large field in the case of the "rigid" connection, and with a small field in the case of the delayed connection. However, this explanation led to another question: why does changing of the conditions lead to a change in the size of the operational field? Usually the rule is that narrowing of the operational field is observed during enhancement of visual attention. Did our conditions cause different degrees of visual attention? In order to answer this question, we shall have to go beyond the limits of the visual system, and examine its functioning in a wider context, i.e., in the context of the condition of solving of the general problem. We can see here that in the first set of conditions, the target "obeys" the subject, in the second case it is almost completely uncontrollable (the delay of the handle is commensurate with the period of accidental perturbation of the target). The situation of the second set of conditions resembles the fantastic cricket game described by L. Carroll, where the players used the coiling necks of flamingoes as bats. It is easy to imagine that the characters of the tale could literally not take their eyes off their "bats" in order to hit the ball. In the first set of conditions, the handle was connected with the target as rigidly as is the handle of a cricket bat with its hitting surface. As a result, the subject has the possibility of obtaining additional information on the movement of the target from the system of control of the hand movements. This took off a considerable amount of load from the vision, leaving it with only the function of "punctuated" supply of information about the target. In the second set of conditions, the information about the displacement of the target could be obtained by the subject <u>only through vision</u>. The "responsibility" of vision was increased, and as a result of this, the visual attention was enhanced. In T. M. Buyakas' opinion, an additional evaluation of the target speed was also accomplished in the second set of conditions, which was absent in the first. The arguments presented here require, of course, further thorough investigation. Thus, in the examined examples, the problem yields actions — hand movements, 1; the conditions of its solving — the type of transmission function or "operating conditions" — determine the degree of participation and the working method of vision: "punctuated" or continuous inflow of visual information, larger or smaller /13 operational field, 2; the eye movements are subordinated to the visual mechanisms and service their work: stabilization in the zone of the marker or accurate followup, 5, 6.

We are left with examination of one more remarkable relationship illustrated in the same Figure 3, by means of arrow 9.

There is evidence according to which the eye movements are directly related to movements of the hand. This is very clearly shown by recent data of T. M. Buyakas and Yu. B. Gippenreyter. The experiments were performed with the previously described setup, which allowed the subject to induce the movement of the visual goal by means of the movement of his own hands. The subject was asked to follow at the same time a signal with his eyes. It appeared that the lag of the eyes which is typical in the followup of an "external" signal, disappears, and the eye moves <u>perfectly synchronously with the self-controlled target</u>. Special tests were carried out in order to find out which signals from the hand movements have access to the eye, whether the proprioceptive or the affector ones (efferent copy, according to Von Holst, 1954). The answer appeared to be in favor of the latter. Figuratively speaking, the eye "knows" what the hand is going to do, and either does it together with the hand or takes it into account in some other manner. An example of this "other manner" was observed by us in experiments performed together with V. Ya. Romanov and S. D. Smirnov (1969). The subject had to count with the eyes vertical lines which formed a uniform "palisade". Usually he did this by "sorting out" each line with his eyes: the recording contains the same number of jumps as there were vertical lines in the object. However, if the hand was included in the process of counting (the subject was asked to mark each line by pressing a button), the eyes stopped doing frequent jumps, and started to move smoothly along the object. In other words, the function of discrete marking of the object's elements was transferred from the eye to the hand.

Finally, let us present a diagram for the case of lack of visual afferentation of the main action. As an example, let us take the automated hand movement which serves muscular proprioception (Figure 3b). Arrows 1 and 3 indicate the main actions, arrow 2 — the requirement for proprioceptive afferentation. The visual system with both its blocks — the visual mechanisms /14 and the eye movements — is "out of business". As mentioned before, a liberation of the reflex processes, in particular of the low level eye movements, is observed. The latter can be represented as the result of the direct action of stimulation, 4. In addition to the visual stimulation, another for example, vestibular, stimulation can be considered here.

We can now ask the following question: what is the sense of the above performed classification of the problems, and of the description of the diagrams illustrating the interactions within each problem in the language of the activity series? What is the use of these diagrams? How do they work?

First of all, these diagrams help to explain the extraordinary variety in eye behavior under identical visual conditions. We saw by means of the above-presented examples that sometimes the eye movements express directly the purposeful actions of the subject, while at times on the contrary, these take place due to congenital, morphologically reinforced connections. However, in the great majority of cases, they depend on visual mechanisms and can be understood as a result of their properties and method of functioning.

On the other hand, determination of the concrete place of eye movements in the structure of human activity is required in order to perform correctly the work "in the reverse sense", in other words to use eye movements for investigating the processes of visual and general activity. Each time, as we attempt to analyze the eye movements in the obtained recordings, we are compelled to reconstruct those processes, which were reflected in these movements, i.e., to formulate hypotheses regarding the properties of visual mechanisms, of algorithm and of the structure of general human activities. The next stage is, of course, the testing of these hypotheses. However, analysis of the eye movements can again play a not insignificant role. The described diagrams indicate the way to such a "reconstruction" work, and, this is their second role which has greater value for us.

Let us examine concrete examples of utilization of eye movements in the investigation of processes which go beyond the limits of operation of the oculomotor system proper.

Let us start with the processes of vision. The very first possibility given by the recording of eye movements, consists in dividing the visual mechanisms into those which assume the obligatory participation of the phasic eye movements (let us call these arbitrarily "dynamic"), and those which take place without
them (arbitrarily named "static"). Obviously, with regard to /15
the work of the first mechanism, the analysis of eye movements may give important additional information. As an example, let us present the investigation of the still controversial question on the role of "muscular sensation" in the mechanisms of spatial vision. In investigating this question by means of data from the comparative estimation of the length of segments, we found no correlation between the amplitude of the eye jumps and the length of the compared segments (Borozdina and Gippenreyter, 1969). This result is in disagreement with the assumption made in the spirit of motor theories, that jumps serve for recoding of the visual length into innervational or muscular proprioceptive pulses, with their subsequent analysis and, by this means,

estimation of the line length. At the same time, the persistent occurrence of eye jumps in the threshhold zone attested to an important role which these may play. We assume that this role consists in increasing the number of projections of the segment on the retina and organization by this means of purposeful variations of the visual signals proper concerning the line length. Variation caused by one and the same source yields more concrete information about it, and facilitates evaluation of its spatial properties.

An analogous hypothesis on the relation between spatial perception and the organism's own movement, in particular, on the role of "visual kinesthesia" (J. Gibson), or "proprioception in the wider sense" (Ch. Sherrington, N. A. Bernshteyn) in the mechanisms of spatial vision, is upheld by many contemporary authors (Held, 1963; Kliks, 1965; Gibson, 1969, as well as a review on this subject by Bem, 1967). In this context it is important for us to emphasize that both the formulation and the testing of such hypotheses are based on the analysis of movements in the organism, including eye movements which are accompanying the act of perception.

The following example refers to the investigation by means of eye movements of the operational field which belongs to the category of "static" vision mechanisms. The history of this matter is very instructive. In the beginning, the term "operational field" was introduced by us in order to explain the fact that fixation of the eye never covers the whole field of the object, but is distributed instead, over the field with a certain density which can sometimes be very small. It was natural to assume that this is due to the ability of vision to process information simultaneously inside the limits of a certain zone, which was called by us working or operational field of vision (Gippenreyter, 1964). Thus, initially, the "operational field" indicated a hypothetical visual mechanism, which was supposed to explain the nature of eye movements, and in particular, the distribution of fixations on the object. However, it became clear immediately that the importance of this mechanism is much greater and goes far beyond the limits of processes in the oculomotor system. A whole series of fundamental problems belong here, such as units of perception and their changes in the process of perceptive development, types and levels of processing of visual information, perceptual attention, etc. Regarding manifestation of the work of this mechanism in the eye movements, this can be used for methodological purposes and made into a method for studying the operational field. In other words, the primary relationship can be reversed: the frequency of fixation can serve as an indicator of the dimensions of the operational field in investigating those factors which influence its dynamics. Experiments in this sense were started by us together with M. D. Gustyakov and M. A. Kareva (1968) and are still continuing today (see the article in the present collection). Let us note, that the operational field is being investigated by us also by other methods, such as recording the distances over which the eye "leaves" the moving object (T. M. Buyakas and V. V. Lyubimov), the method of induced nystagmus (V. Ya. Romanov) and so forth.

As a third example, let us present investigation of a phenomenon which belongs not to visual processes, but instead to processes of the general activity. These processes have an even more remote and even more mediating connection with the eye movements, and nevertheless they can sometimes be better understood through the latter.

We are dealing here with a phenomenon which was observed in the work of V. V. Lyubimov. The experiments were performed with the same setup, the same problem and under the same conditions as the above-examined experiments of T. M. Buyakas. It was found that if the target (the position of which was controlled by the subject) was presented on a <u>moving background</u>, a persistent asymmetry of the error of manual tracking appeared. However, this effect occurred only when the influence of the handle on the target was delayed (second set of conditions) and was never observed when there was a "rigid" connection between handle and target (first set of conditions).

In attempting to explain the obtained findings, the author assumed that the described asymmetry is related to an erroneous evaluation of the speed of the target on the moving background: the speed of the target was underestimated when background and target moved in the same direction, and was overestimated when target and background moved in opposite directions. The subject acted (erroneously) in accordance with the perceived speed, insufficiently compensating for the deviation of the target in the first case, and compensating excessively in the second case. As a result, during the greater part of the time, the target was on one side of the mark, and this led to the asymmetry of the erroneous tracking. /17

However, this explanation leaves open the following question: why was the asymmetry of the error not observed in the first set of conditions? The author considered several hypotheses as possible answers. We shall only dwell on one of them here.

As was said above, analysis of the eye movement shows that in the first set of conditions, the work is performed with a large operational vision field, while in the second set of conditions this field is much smaller. It is known from investigations of the illusion of induced movement that an illusion appears when the attention is concentrated on a small object-figure, and disappears when the attention is distributed over a wider area of the moving background (Duncker, 1938). It is easy to see that the method by means of which the vision operates in the first set of conditions corresponds exactly with the conditions of illusion disappearance, while the method used in the second set of conditions corresponds to the conditions of its appearance. It remains to be added that the name illusion relating to the moving signal indicates exactly the underestimation of its speed in one direction, and its overestimation in the other. We should like to emphasize the very peculiar situation in which the visual system of the subject was found in the second set of conditions. The narrowing of the operational field to the dimensions of the target was a useful "reaction" of vision to the more complex general working conditions. However, due to the movement of the background, this useful reaction became at the same time the cause of a perceptive illusion. It seems that the visual system fell into a vicious circle: the method it used for a more accurate evaluation of the speed of the target led to an erroneous evaluation of that same speed. The eye movements served this method, i.e., the work with a small operational field, and at the same time became the involuntary "collaborators" of the process leading to the illusion. From a methodological point of view, they became the main link by means of which the "lengthening" of the whole chain of events was promoted, starting with analysis of the conditions under which the handle influenced the target, and ending with the operator's error.

Until now, we discussed primarily the phasic eye movements. However, a no less important and perhaps even more essential form of eye "movements" which serves vision, is their tonic variant — the fixations. It is known that the eye fixations occupy 95 to 97% of the overall time of looking (Woodworth, Schlosberg, 1958); during fixations, the main visual work is carried out, the phasic eye movements — the jump, usually only prepare the conditions for this work.

The visual process taking place during fixations varies according to many parameters, it can change along the lines of intensity, saturation, activity, randomness, scope, and so forth. No wonder that a large number of terms are used in the language which reflect the degree of activity of vision, the method or manner of looking, the degree of interest in the visual act, etc. Thus, one speaks about "persistent" or "piercing" glance. The same glance may be "nonsensical", "absent", or "empty". It is possible to "turn" the gaze, to "run over" with the eyes, or to "take in" a picture with one glance; one speaks about "staring at", or "goggling at" something, looking "with the corner of the eye", etc. Behind all these accurate words and expressions, an important psychological reality is hidden, which we can very well feel but which we can as yet very poorly analyze. For example, in all the enumerated cases, the recordings of eye movements gave the same "dumb" fixation dots, which externally could be distinguished from each other. The only variable parameter of fixation is their duration. However, the duration of fixation has no strict correlation with the content of the process underlying it. As shown by numerous studies, including ours, the duration of fixations may increase both in moments of intense mental work and during the increase of visual strain (Tinker, 1951; Gippenreyter, Kareva, 1968; L. V. Borozdina, O. V. Kon'kova and others). /18

If we were to use a figurative comparison, the recordings of macromovements of the eye can be on the whole compared with the results of the degenerate geometric transformation, given for example, by the projection of a three-dimensional body in a plane. As is known, it is not possible to reconstruct the lost third dimension according to such a projection. Exactly in the same way, the recordings of eye movements do not allow one to reconstruct the engaging-dynamic aspect of the vision process. The "degenerate" character of the recordings sets the limit to the method of eye movement recording in its traditional form.

As we constantly ran into such boundaries during our investigation, we felt an increasing sense of frustration, which led us to the search for new methodological ways.

The question arose whether it was possible to make fixations "talk", i.e., to find such properties or parameters of the fixation movements by means of which it would be possible to learn how does man look in a given moment, or how does he look in general? In connection with this question, we started investigating fixation optokinetic nystagmus (FOKN) and dynamic fixation.* These marked the transition to investigation of the tonic eye movements, and eye movements in the micro range. /19

We should like to mention here a curious fact. The purpose of our first studies with recording of the phasic eye movements was to find out how does the problem affect eye movements, what are their quantitative characteristics, their mechanisms, etc. In other words, initially the object of our attention was the eye movements themselves, and only later, in the course of the experiment, did certain potentials of their utilization for the study of a larger circle of topics appear.

Contrarily, we turned to the fixation eye movements with a clear methodological purpose; however, the logic of elaboration of the method required its transformation into the topic of the investigation in the first place.

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* Dynamic fixation can be classified both with the phasic and with the tonic forms of eye movement. While the former is determined by the displacement of the eyes in the environment, the latter is determined by stabilization relative to the examined object. Classification of the indicated type of eye movement with one or the other form depends on which aspect is highlighted in the investigation.

According to this logic, the first experiments were performed in order to study the properties and the mechanisms of the FOKN, and theyyielded a series of previously unknown physiological findings (Gippenreyter and Romanov, 1970). Certain types of tracking movements of the eye were revealed and described in an attempt to analyze their levels (Gippenreyter and Smirnov, 1971). In this work, the questions on the mechanisms of fixation eye movements, were practically only presented. However, the obtained results assisted in making step in a direction which was important for us: starting the investigation of the connection between the fixation eye movements and the engaging — dynamic aspect of the visual process and of activity in general.

The movement in this direction was determined as early as the formulation of the above representations on the general structure of activity and the variable functional role of eye movements, depending on the problem (see diagrams, Figures 1 - 3). Only in this case, the fixations in their static or dynamic form appeared instead of the eye movements proper. By presenting the subject with various problems, we placed the fixations either in a position of main actions (in the problem of fixating the dot) or of operations in the main actions (visual problem), or else of secondary actions (mental problem with simultaneous fixation of the dot). The main finding obtained in this case consisted in clear and regular changes of the fixation nystagmus. Subsequently the various relationships between the brain centers which participated in the organization of the fixation eye movements were examined (Gippenreyter and Romanov, 1970). Analogous effects with regard to their sense but of different form were obtained from dynamic fixation data (Gippenreyter and Smirnov, 1971).

The detected dependence of the mechanism of fixation on the context of the activity was not altogether unexpected, but at the same time appeared as fairly new.

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The decisive effect of the "content" and "sense" structure of the problem on the level of movement formation was convincingly shown in the studies of N. A. Bernshteyn (1945, 1947, 1964), A. N. Leont'yev and A. V. Zaporozhets (1945), V. S. Gurfinkel, Ya. M. Kots and M. Ya. Shik (1965) and others. However, in these works, only the motor problems addressed to skeletal muscles were examined. The eye movements in this plane were never discussed, perhaps because they were justly connected with perceptive problem solving. We could of course not say in advance that the level of the eye fixation movements would depend on the content and sense structures of a parallel activity.

The next important step was made in the study of V. Ya. Romanov. By presenting the subject with only visual problems, i.e., by maintaining the macrostructure of their activity unchanged, he revealed the sensitivity of FOKN to such subtle and, at the same time, important psychological properties of the visual process as its randomness (random and nonrandom reversal of ambiguous figures), activity and intensity (active and passive discrimination of more or less disguised figures). This result together with the previous ones showed that the hope of maintaining the "third dimension" by means of fixation eye movements recordings, appeared less unrealistic.

The extension of the FOKN studies to a wider range of problems has brought new results. In the just mentioned study of V. Ya. Romanov, at least two remarkable findings were obtained. The first of these findings concerns the reactivity of the FOKN parameters to the change of the area of attention adjustment. This finding was very valuable to us, inasmuch as for the first time, after many years, the operational field of vision was seen in its direct manifestation. Until that time, it was merely a useful hypothesis.

The second finding belongs to those phenomena in which the method of self-observation was exclusively prevalent until that time. We mean the hidden forms of the work of vision, the visual activity observed in the absence of real objects. Internal visual images, representations, diagrams, standards, etc. are involved in many types of psychic activity. This is reflected in such traditional terms as visual memory, figurative thinking, visual control of movements, etc.

While recording the FOKN during the solving of thinking problems, V. Ya. Romanov detected two opposite types of FOKN: /21
"visual" and "mental". Upon questioning the subjects, it appeared that those who solved the problem in the visual plane by representing the object and the operations with it, ("sawing" of the colored cube) had a "visual" FOKN, while those subjects who solved the problem by a pure logical method presented accordingly a "mental" FOKN. This result, which was subsequently confirmed by analysis of the FOKN in a subject with a unique ability for visualization, showed that the FOKN parameters can reflect the participation of vision in the internal psychic processes or internal psychic activity.

This question became the topic examined in the work of Yu. B. Gippenreyter and G. L. Pik, using motor problems. The characteristic feature of these experiments was exclusion of the external visual control of the movement (the subject was asked to perform a certain movement with the hands without looking at the hands). It appeared, that despite the indicated limitation, the FOKN assumes a more "visual" character during those movements which required, by the conditions of their organization, the hidden participation of vision. From the external behavior of the eyes, it could be concluded that the subject seemed to follow the movements of the hand by an internal glance. The oculomotor manifestations of the work of internal vision included in the manual motor problem were observed also in the investigations of T. M. Buyakas and Yu. B. Gippenreyter, where due to a special organization of the experiment, it was possible to present problems which were addressed to the external and to the internal vision, and subordination of the eye movements to the latter was observed.

In the already mentioned work of Yu. B. Gippenreyter and G. L. Pik, another entirely new property of FOKN was found. It appeared that its rapid phases coincided with definite events in the hand, i.e., the completion of one "portion" of the movement and the beginning of the next. These coincidences were observed in motor problems which assumed participation of vision in an apparent or hidden way. The described findings led to the formulation of the well-founded assumption that the cycles of FOKN reflect "quanta" of visual attention, or units of purposeful activity. The first supplementary findings seem to confirm this hypothesis. For example, it was made clear that the magnitude of the units detected by the FOKN cycle depends on the automation of the movements: the more automated the movements, the larger the units (for example, the signature as compared to the reproduction of words in block letters). It seems to us that the latter result opens exceptionally wide perspectives. It may be hoped that the FOKN will prove to be a method of analysis of the activity structure, not only in its "totality" (presence and "specific weight" of the visual component), but also in "sequence" (division into separate actions). We would /22
like to emphasize in particular that such a possibility was noted with regard to the internal activity; the structure and dynamics

of the latter have appeared until now only in the most general assumptions.

In concluding, we shall attempt to determine the general importance for psychology and the prospect of the trend relating to the above described study. For this purpose, we shall have to touch upon certain points in the modern theory of activity, which mark at the same time its "blank spots" and its "growth points".

The main notion in this theory is the action which is determined as a process subordinated to the goal, or directed towards achieving the goal. Most human goals involve a succession of actions rather than single acts. Each partial action has apparently its own intermediate goal. In other words, the main goals can be subdivided into subgoals, which in their turn can yield goals of a lower order, etc. The sequence of the partial action may be complex and hierarchically organized. As a rule, it includes alternative selections, unsuccessful tests, and the search of detours, transition to actions of a lower or higher order, etc. In view of the exceptional complexity and the dynamic nature of the "flow of activity", there appears the problem of its analysis. What are the means available to us for this analysis?

First of all, knowing the goal and the external conditions, an external description of the required composition and sequence of actions, can be given. Obviously, one of the factors determining the algorithm of activity is the "logic" of the objects seized by the subject, or the "logic" of the environment (including the social one) in which the subjects act. Such algorithms are as a rule, singled out by the social experience of man and are fixated in the form of standards, programs, goals, methods, etc. Every man, in order to realize successfully his

goals, must appropriate these standards, rules, etc., and act in accordance with them. However, this is only one side of the matter. The ascribed plan or program of action does not determine the psychological composition of the activity. The latter is formed as a result of the clash between the problem and the available means of the organism, first of all its operations and functions, which are the ready-made and acquired tools of activity. The outlined plan or program are realized with these means and are inevitably transformed by them. Certain concrete actions may be accomplished by the operation of physiological mechanisms, and in that case, the subject simply makes use of /23
the ready-made result in his activity. Another programmed action may on the contrary prove to be poorly provided for "below" and then strained and clumsy tests appear, fractionation of the action into smaller actions, reformulation of the problem, etc. From the viewpoint of logical analysis, every act which is directed to achieving the goal, including intermediate goals, can be regarded as an action. From a psychological point of view, this can be regarded as an action, operation, and finally as a function. Where in the set of hierarchically constructed acts do the actions end, and do operations and functions begin? We cannot answer this question from the outside, since we do not know what appears to the subject in a given moment as the goal. Self-observation is also of little use here, since it replaces the "business" goal, by a reflex goal, and in so doing, destroys the process which we want to investigate.

According to one opinion, the composition of the activity can be learned if it is formed under rigorously controlled conditions. However, in our opinion, this viewpoint also reflects the logical approach, since any attempt to form a new action is calculated for the initial potential of the organism. The internal means of the organism and of the subject realize the "teacher's" intention by transforming it into the form of concrete live action. They determine not only the primary unfolding of the process according to levels, but largely also its further phase. The organic basis of the actions appears, for example, in such highly important processes as the interiorization and automation of action. These processes lead to particularly marked structural transformations of activity. In particular, as was convincingly shown by Soviet investigators, the development of any habit, whether motor, object-tool, perceptive or mental, follows the path of automation of action, their transformation into operations, as well as merging of the partial actions into larger ones (Bernshteyn, 1947; Leont'yev, 1965; Zaporozhets, 1967; Gal'perin, 1959 and others). However, the functional-genetic method gives no accurate answer to a whole row of questions, such as when does a given action become an operation, what is the initial composition of the actions, what are the larger units formed by these actions, what are the structural changes undergone by the new actions in their turn, and other extremely important questions. While an attempt can be made to solve such problems by an analysis of their objective properties, such as speed, extent of merging, sterotypy, etc., with regard to external actions, the problem becomes particularly difficult with respect to internal action.

Elaboration of the methods of activity analysis is of course one of the main problems in psychology. Its solution involves the search for indicators of the levels, structure and dynamics of activity processes. The eye movements can be fully utilized as one such indicator. This is the conclusion to which we have been led by investigations of both phasic and in particular, tonic, eye movements. Among these are findings which indicate the dependence of the macro behavior of the eyes on the problem and stages in its solving; the dependence of eye movements on the type and conditions of operation of visual mechanisms; findings which show reorganization of the fixation mechanisms as a result of a change in the degree of eye fixation in the activity structure, as well as of the engaging-dynamic characteristics of the visual process; reflection in the same mechanisms of the degree of participation of vision in nonvisual types of activity — movements, thinking, etc., the remarkable ability of FOKN to "dismember" the continuous process of activity into separate units, as well as revealing the dynamics of these units.

Eye movements represent a unique material in the methodological sense. They are literally in the center of psychic life as they are included both in the processes of image creation and of behavior control. In the eye movements are "projected" processes at various levels, from conscious actions to morphologically reinforced functions. Harmonically combining processes of such different nature, the eye movements dictate the ways for complex multilevel investigation of the activity.

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